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## Snowmelt Lysimeters Perform Well in Cold Temperatures in Central Colorado

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Comparison between lysimeter and snow-tube measurements of melt rates indicated that the lysimeters provided reliable measurements of snowmelt. The lysimeter frame did not noticeably affect the thermal regime of the snow within the lysimeter.

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Reliable measurements of daily snowmelt can provide information for forecasting residual volume and streamflow, for development and testing of snowmelt models, and about the effects of various forest environments on the snowmelt process. A snowmelt lysimeter recently designed by Haupt (1969a, 1969b) is capable of measuring this parameter.<sup>2</sup> His lysimeters have been used extensively at Priest River Experimental Forest in northern Idaho where relatively mild winter temperatures prevail (Haupt 1972). Before they could be used in snowmelt studies in the central Rocky Mountains, we needed to know how these lysimeters would perform under severe cold temperature conditions—such as those found at Fraser Experimental Forest, Colorado.

### Lysimeter Design

Haupt's lysimeter measures melt percolate as it emerges from the base of the pack. Melt water is allowed to drain through the pack, where it is funneled into a tank, and measured volumetrically with a water-level recorder.

The lysimeters used in this study are almost identical to Haupt's. A few minor modifications were made to reduce costs and to make the lysimeters more portable.

The lysimeters consist of a trough assembly (fig. 1), and a catchment tank with a water-level recorder (fig. 2). These two units are connected with a plastic drain hose buried at a sufficient depth to prevent freezing.

A trough is 58 by 43 by 25 centimeters(cm), with an outlet drain at its base. For insulation and filtering, a layer of litter is supported in the bottom of the trough by a wire mesh screen reinforced by steel bars. The barrier support frame is attached to the corners of the trough and supports a white, opaque polyethylene barrier which is pulled up the frame at intervals during the snow accumulation period. At the beginning of the melt season, the barrier support frame is removed, which leaves an isolated, undisturbed column of snow within the polyethylene barrier.

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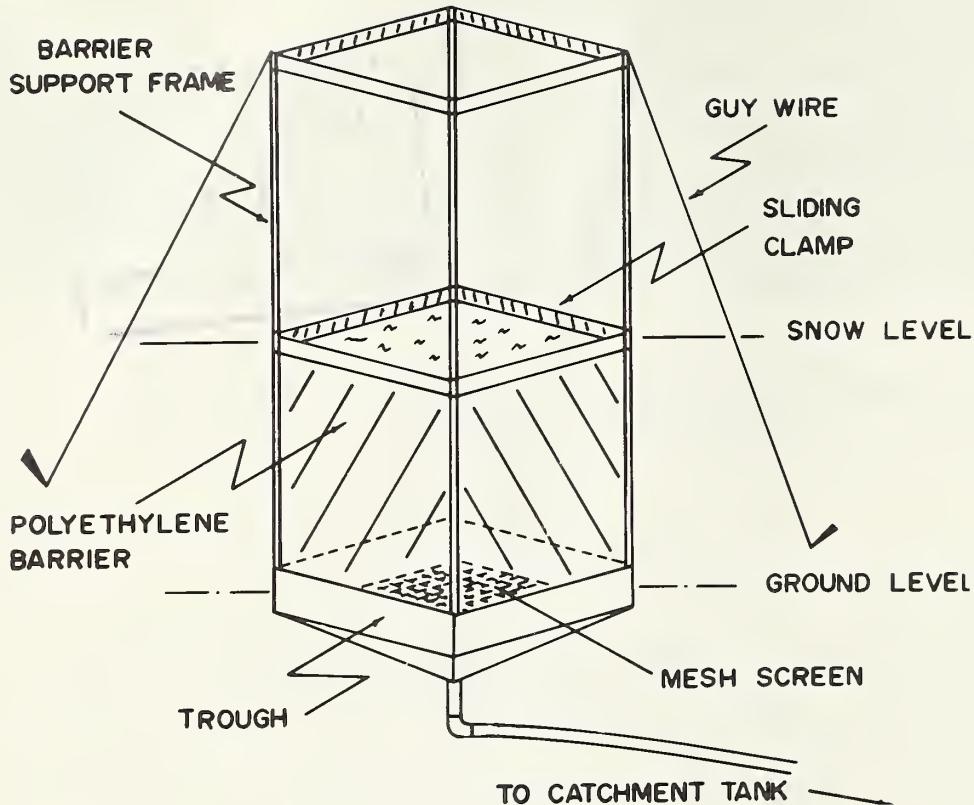


Figure 1.--Barrier support frame of snowmelt lysimeter.

Melt water drains by gravity into the catchment tank. The tank consists of a 55-gallon drum with a 25 by 25-cm entryway centered at the top. A water level recorder is supported over the entryway and covered with a small instrument shelter. Operation of these lysimeters is described in detail by Haupt (1969a, 1969b).

The cost of the materials for each lysimeter, less the water level recorder, was just under \$100.

#### Description of Study Site

The study was conducted on West St. Louis Creek watershed, a small drainage basin on the Fraser Experimental Forest. The site was in the upper reaches of the watershed at an elevation of 3,140 meters (m) on a south-facing slope (22 percent average gradient) beneath a fairly uniform subalpine forest.

#### Climate

The climate at Fraser Experimental Forest is characterized by long, cold winters, and short,

cool summers. The average yearly temperature for 12 years of record was 0.5° C. The mean monthly temperature was -10.0° C for January and 12.6° C for July (Haefner 1971).

Precipitation at the Experimental Forest is mainly in the form of snow. Snow cover usually becomes permanent by late fall and remains until May or June. Throughout the winter, the pack remains well below freezing and does not begin to melt until late March or April. At an elevation of 3,200 m, Leaf (1969) found that the peak snow accumulation for an average year amounts to about 37 cm of water. During the melt season, an additional 13 cm of precipitation, generally in the form of snow, is added to the snowpack, increasing the average yearly melt to 50 cm.

#### Vegetation

An even-aged stand of lodgepole pine formed the upper stratum of the stand. Engelmann spruce and subalpine fir, shade-tolerant species, formed an uneven-aged, multi-leveled canopy beneath the lodgepole pine. The dominant trees on the study site averaged 14 m,

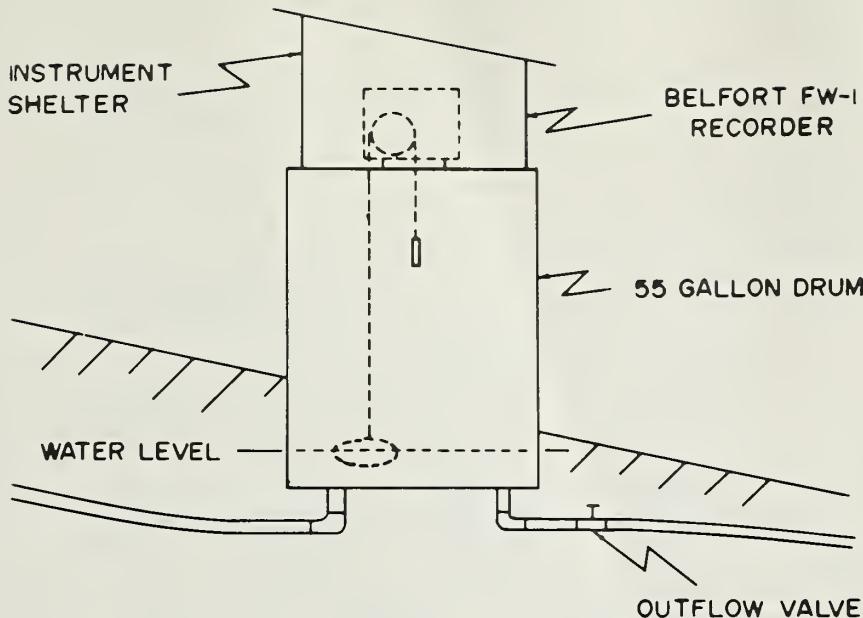


Figure 2.--Catchment tank of snowmelt lysimeter.

ranging from 11 to 21 m, and had moderately developed crowns. Crown closure, as measured by the vertical crown projection method, was approximately 53 percent. Basal area averaged  $49 \text{ m}^2$  per hectare (ha) with a density of 850 stems/ha. Average diameter at breast height (d.b.h.) was 29 cm for the lodgepole pine and 14 cm for the Engelmann spruce and subalpine fir. Understory vegetation was composed almost entirely of a dense mat of grouse whortleberry.

#### Data Collection

Four snowmelt lysimeters were situated at the study site about 40 m apart and spaced along the same contour. Each was under forest canopy representative of the area. To avoid point locations which would be influenced by abnormal melting conditions, lysimeters were placed at least 2 m from the nearest tree bole or fallen tree. Lysimeters were not located in local depressions or small drainages where cold air drainage might influence melt rates.

Data collection began on March 24 and continued through June 23, 1971. Precipitation and

snow water equivalents were measured at weekly intervals beginning March 31, while snow temperature profiles were recorded through April 8. Snowmelt was recorded continuously throughout this period by the lysimeters.

#### Lysimeter Melt

To obtain daily snowmelt rates for each lysimeter, the data were first analyzed to determine if melt water was delayed enroute through the pack. Outflow at 3-hour intervals was obtained from the water-level charts. Melt water had usually drained completely by 0600 hours (h) the following day (fig. 3). Melt water outflow from 0600 to 0600 gave the quantity of daily melt, and no corrections for delayed routing through the pack were necessary. Anderson (1968) and Leaf (1966) also found that, for a snowpack less than 1.5 m in depth, the free water in the pack drains almost completely by the following morning.

Cumulative daily melt values reveal that snow in lysimeter 2 melted more rapidly than

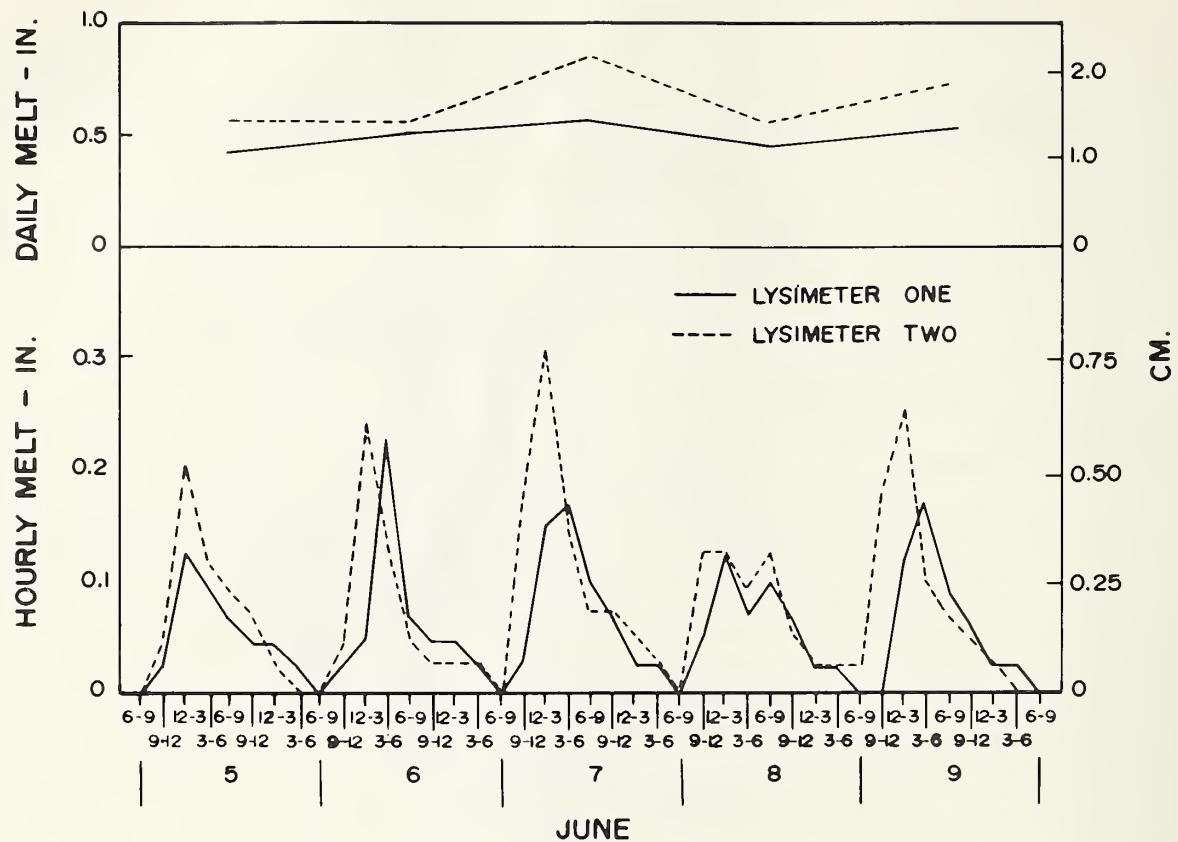


Figure 3.--Average hourly snowmelt by 3-hour intervals for lysimeters 1 and 2. Snow depth during this period averaged 100 centimeters. Snow density averaged  $0.45 \text{ gm/cm}^3$ .

in lysimeters 1, 3, and 4 (fig. 4), perhaps because the canopy to the south of lysimeter 2 was more open than that to the south of the other lysimeters.

#### Lysimeter Performance

There is a question about the effects of the polyethylene barrier on the thermal regime of the snowpack during accumulation and melt. Although the polyethylene barrier is an obstruction to horizontal water and heat transport, intercepts shortwave energy in the upper portion (25 cm) of the snowpack, and absorbs sensible heat and longwave radiation at the surface of the pack, the integrated result on the energy exchange within the isolated snow column is not known.

To learn more about this effect, snow temperature was measured to the nearest  $0.1^\circ \text{C}$  at the end of the accumulation season to assess the effect of the polyethylene barrier on the vertical temperature profile within each snow

column. The temperature probe consisted of a thermistor unit mounted on a pole 1.5 cm in diameter (Swanson 1967). Vertical temperature profiles were obtained within each lysimeter snow column and at three sample points outside. Measurements were taken on March 24 at lysimeters 1 and 3 and on March 30 at lysimeters 2 and 4. Because only one temperature profile was taken within each snow column in order to minimize disturbance to the snow within the plastic barrier, a statistical analysis was not possible. Instead, a simple rational approach was taken.

Variation between the snow temperature profiles inside and outside of a lysimeter snow column was greatest at lysimeter 1 (fig. 5). The mean of the three temperature profiles adjacent to each snow column and the temperature profile within each snow column are illustrated in figures 6 and 7. At any given depth, snow temperatures within and adjacent to the snow columns differed only slightly.

There also was little difference in the cold content between the mean outside snowpack

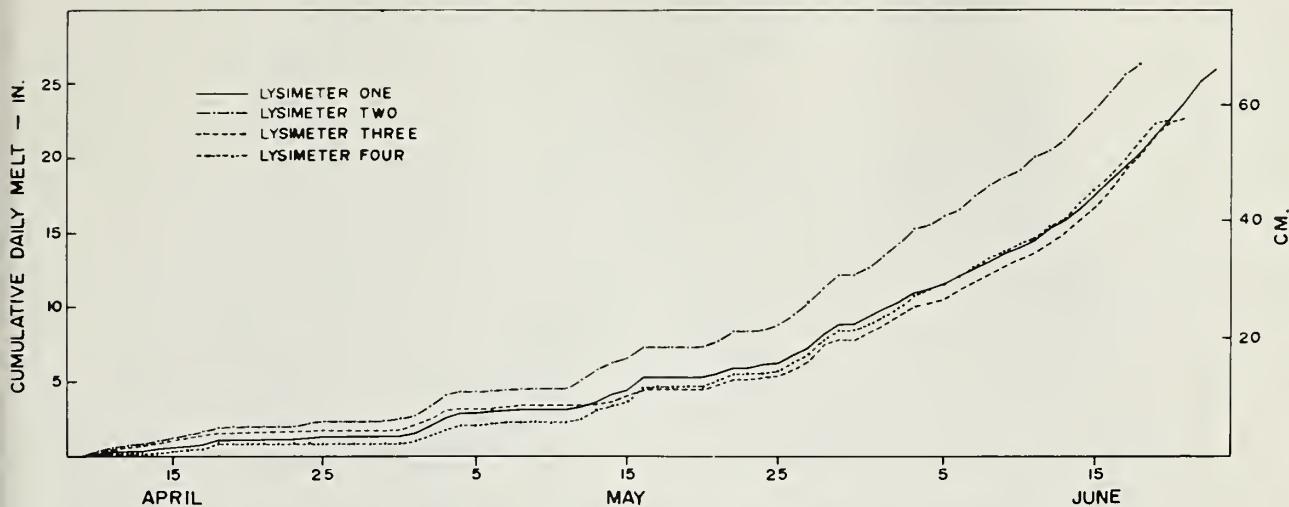


Figure 4.--Cumulative daily snowmelt at each lysimeter.

temperatures and the lysimeter temperatures. On March 24, the difference in cold content was 8 calories for lysimeter 1 and 5 calories for lysimeter 3, while on March 30, the difference was 8 calories for lysimeter 2 and 0 for lysimeter 4. The effect of the barrier on the time when the pack within the snow column became isothermal was negligible.

To test the ability of the lysimeters to measure melt rates at a point, five snow sample points were located within 3 m of each lysimeter. At these points, snow water equivalents were measured with a Federal snow sampler at weekly intervals throughout the melt season. Weekly precipitation was also recorded at each lysimeter. Average weekly snowmelt calculated from the precipitation data and water equivalent readings was then compared with the weekly melt from each lysimeter.

Average weekly differences and correlation coefficients were calculated to explain the weekly variation between the snow tube measurements and lysimeter readings at each lysimeter site:

Lysimeter	Average weekly difference (cm)	Correlation coefficient
1	+1.30	0.97
2	+ .90	.97
3	+1.60	.96
4	+1.30	.95

Weekly melt rates estimated from the snow-tube measurements were generally higher than those obtained from the lysimeters.

The main reasons for the difference are probably related to (1) the accuracy of the Federal snow sampler, which measures to the nearest 3 cm (Weiss and Wilson 1958), and (2) difficulties in obtaining an accurate series of readings with the snow sampler when air temperature is below 0° C and snow contains free water which freezes to the inside of the snow tube. This freezing occurred on April 27 and May 18, and may have affected melt rates computed from data taken on those dates. The lysimeter measurements are evidently the more accurate of the two.

A second check on lysimeter melt rate was based on the assumption that, on an area with a relatively uniform forest cover at the same aspect, slope, and elevation, quantities of daily melt from any two given points should be proportional from day to day.

Daily melt ratios were computed for each lysimeter. These ratios equaled daily melt over the total melt. For this comparison, total melt was the cumulated daily lysimeter melt to the time when the first lysimeter became bare.

The cumulative ratios with time were very similar between lysimeters (fig. 8). An analysis of variance was made on the daily lysimeter ratios in order to obtain a measure of the variation of the lysimeter ratios within each day. The computed mean variance of melt rates in percent within each day was small, equaling 0.11 percent, which indicated the lysimeters were furnishing good measures of daily snowmelt.

Haupt (1969a, 1969b) reports that the polyethylene barrier generally causes abnormal surface melt at the borders of the snow column.

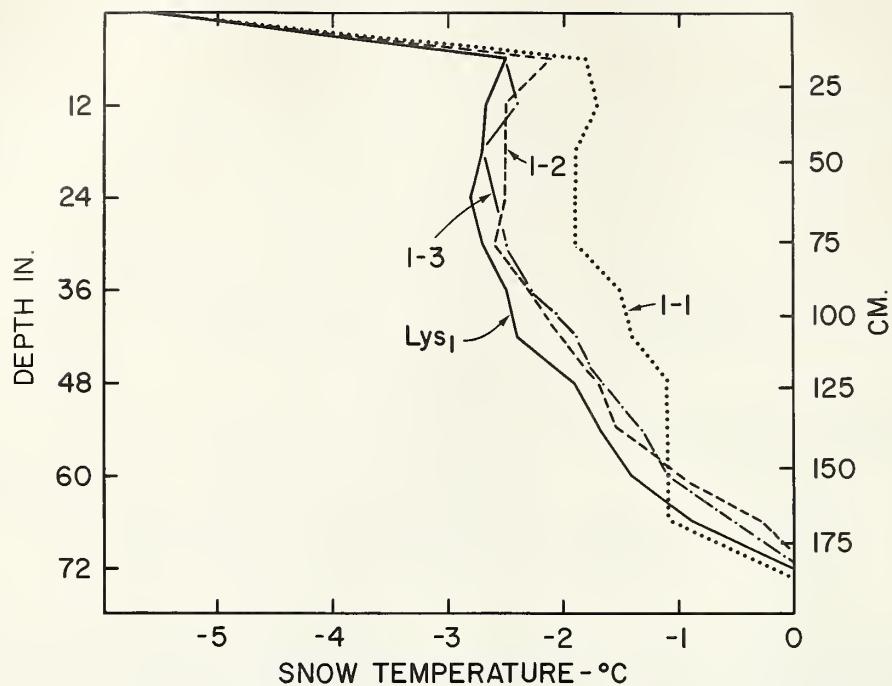


Figure 5.--Snow temperature profiles with depth at lysimeter 1 on March 24, 1971. Profile Lys<sub>1</sub> represents temperature profile measured within polyethylene barrier. Profiles I-1, I-2, and I-3 represent temperature profiles measured adjacent to polyethylene barrier.

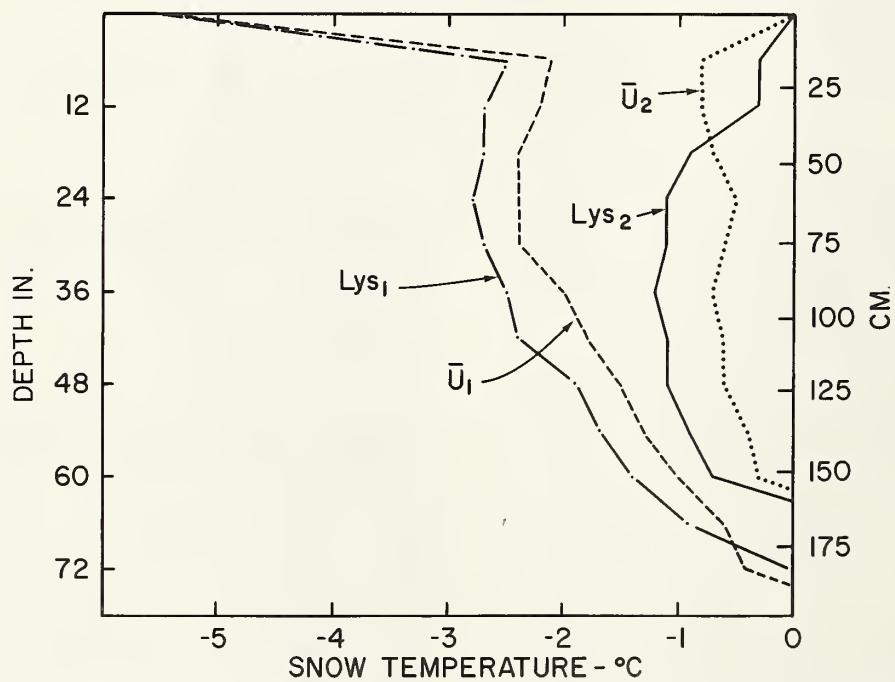


Figure 6.--Snow temperature profiles with depth. Temperature profiles for lysimeters 1 and 2 were measured on March 24, 1971, and March 30, 1971, respectively. Profiles Lys<sub>1</sub> and Lys<sub>2</sub> represent temperature profiles measured within each polyethylene barrier. Profiles  $\bar{U}_1$  and  $\bar{U}_2$  represent the average temperature profile of the three sample points adjacent to each polyethylene barrier.

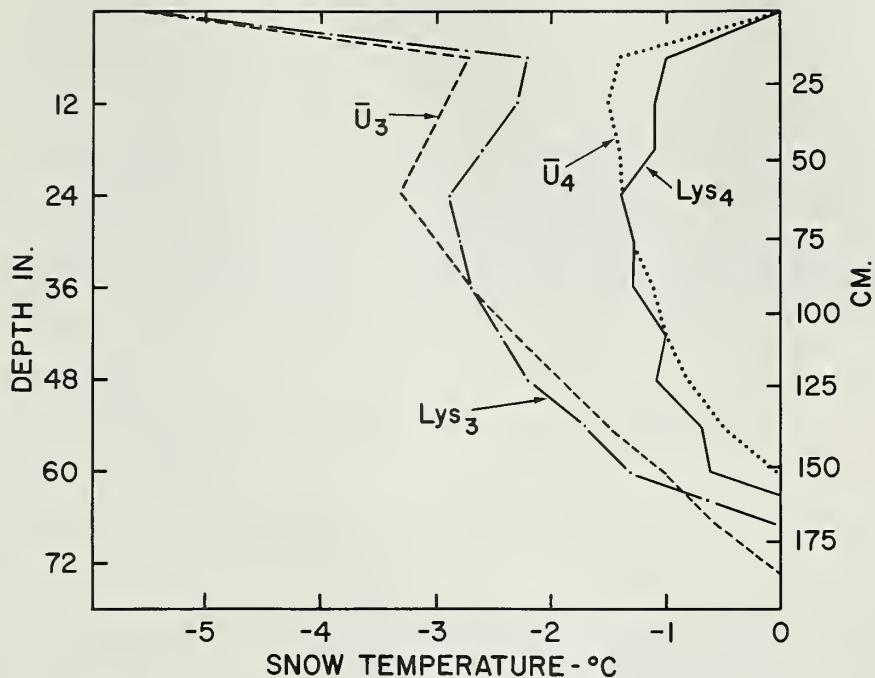


Figure 7.--Snow temperature profiles with depth. Temperature profiles for lysimeters 3 and 4 were measured on March 24, and March 30, 1971, respectively. Profiles  $Lys_3$  and  $Lys_4$  represent temperature profiles measured within each polyethylene barrier. Profiles  $\bar{U}_3$  and  $\bar{U}_4$  represent the average temperature profile of the three sample points adjacent to each polyethylene barrier.

The effect is greatest in the openings and decreases with increasing forest cover. Some abnormal surface melt did occur at the borders of the four snow columns, but the effect was small.

A source of error in the melt measurements was the change in surface area of the snow columns, which were assumed to equal  $0.250 \text{ m}^2$  throughout the melt season. However, on June 9, the surface area of snow columns 1 through 4 was 0.226, 0.250, 0.239, and  $0.226 \text{ m}^2$ , respectively. The decrease in surface area, which ranged from 0 to 10 percent, probably originated during the accumulation period when a snow shovel was used to cut down along the barrier support frame to the polyethylene barrier so that the barrier could be raised. Although temperatures were low throughout the melt season, the melt percolate did not freeze within the drainpipe. The snow was of sufficient depth to prevent excessive heat loss from the ground and the catchment tank during this period.

### Summary and Conclusions

The lysimeters are well suited to the severe temperature conditions at Fraser Experimental Forest. Throughout much of the Forest, melt and rain-on-snow events rarely occur before April. During that accumulation period, melt measurements need not be made, and the lysimeters must be visited only to raise the polyethylene barrier after each 30 to 40 cm of snow accumulation.

Obtaining accurate estimates of daily melt is simplified because melt rarely occurs during the night. Since melt during the day usually drains from the pack by 0600 the following morning, it is not necessary to correct for melt water retained within the pack to obtain a measure of daily melt.

At other locations in the central Rocky Mountains, particularly those with shallow or intermittent snowpacks, some modifications in design may be required to make the lysimeters operational.

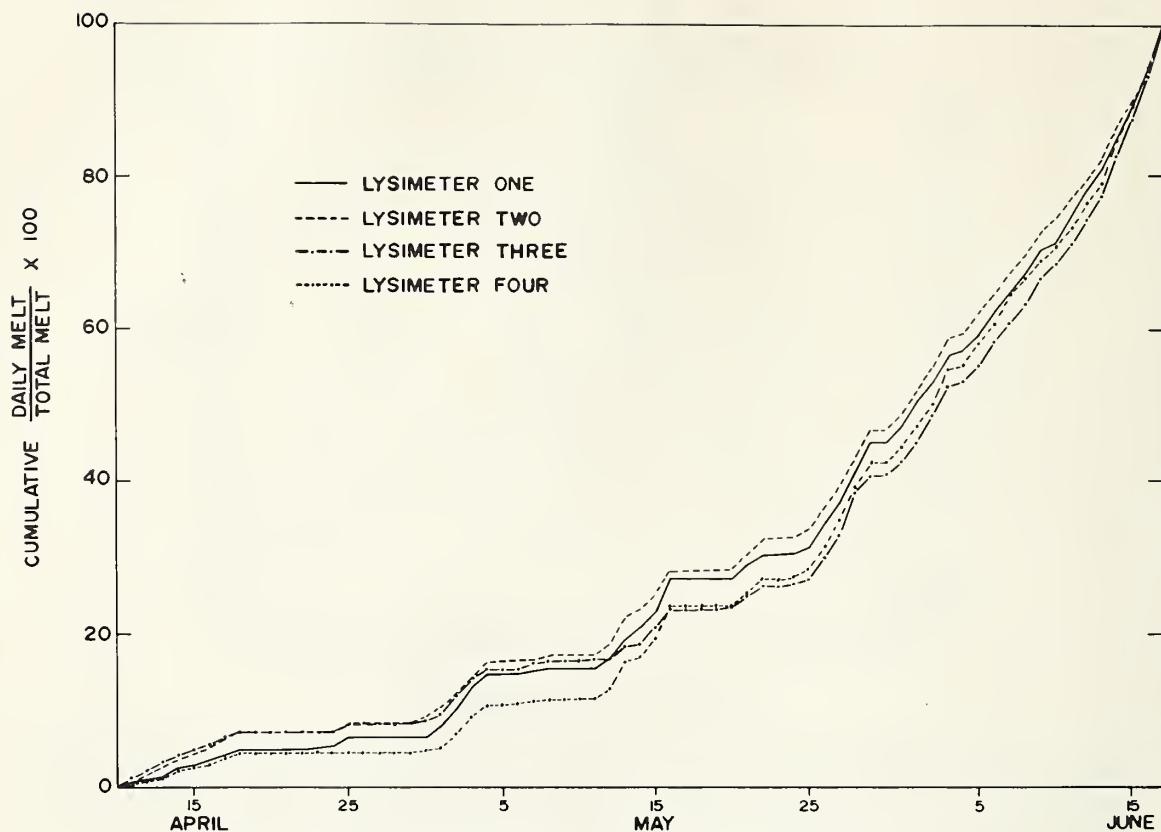


Figure 8.--Cumulative daily lysimeter ratios with time.

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